

COMETARY KNOTS AND BROAD EMISSION LINES, GAMMA RAYS AND NEUTRINOS FROM AGN

Arnon Dar

Department of Physics and Space Research Institute
Technion-Israel Institute of Technology
Haifa 32000, Israel

February 1, 2008

Abstract

Recent observations with the Hubble Space Telescope have discovered in the nearest planetary nebula, the Helix Nebula, thousands of gigantic comet-like objects with planet like masses in a ring around the central brilliant star at a distance comparable to our own Oort cloud of comets. We propose that such circumstellar rings of planets exist around most stars and that the gas clouds which emit the broad optical lines from quasars are radiation ablated planets which have been stripped off by gravitational collisions from stars that orbit near the central massive black hole. We propose that collisions of jet accelerated particles with these targets crossing the line of sight produce TeV γ -ray flares (GRFs) from blazars like Markarian 421 and Markarian 501. Hadronic production of TeV GRFs from blazars implies that they are accompanied by a simultaneous emission of high energy neutrinos, and of electrons and positrons with similar intensities, light curves and energy spectra. Cooling of these electrons and positrons by emission of synchrotron radiation and inverse Compton scattering produces γ -ray, X-ray, optical and radio afterglows.

1 Introduction

In a recent letter we have suggested (Dar and Laor 1997) that collisions of jet accelerated particles with gas clouds in the broad line emission region of Active Galactic Nuclei (AGN) close to the line of sight produce TeV γ -ray flares (GRFs) from blazars like Markarian 421 (Mrk 421) and Markarian 501 (Mrk 501). In this letter we suggest that these gas clouds are ablated planets, like the ~ 3500 gigantic “Cometary Knots” which were discovered with the Hubble Space Telescope (O’Dell and Handron 1996) in a ring around the central star in the Helix nebula. We suggest that distant circumstellar rings which contain thousands of planets may exist around most stars. Such loosely bound planets are stripped off (“planetization”) from stars which orbit near the central massive black holes in AGN by gravitational collisions. They are ablated by the strong radiation field and by gravitational collisions and form the ionization bounded “gas clouds” which emit the broad optical lines from AGN. We also suggest that relativistic jets in AGN act as Fermi magnetic mirrors which accelerate the ionized interstellar atoms in front of the jets to cosmic ray energies.. In blazars, which are AGN with relativistic jets that happen to lie near the line of sight, strong GRFs are produced when Cometary Knots with high column density cross the line of sight near the central black hole. TeV γ -rays are then produced through the reaction $pp \rightarrow \pi^0 X$ which is followed by prompt $\pi^0 \rightarrow 2\gamma$ decay. The production of TeV γ -rays is also accompanied by production of TeV neutrinos, electrons and positrons, mainly via $pp \rightarrow \pi^\pm X$; $\pi^\pm \rightarrow \mu^\pm \nu_\mu$; $\mu^\pm \rightarrow e^\pm \nu_e \nu_\mu$. The subsequent cooling of these electrons and positrons by synchrotron radiation, inverse Compton scattering, bremsstrahlung and annihilation produces γ -ray, X-ray, optical, and radio afterglows. We show that this model reproduces well the main observed properties of GRFs from Mrk 429 and Mrk 501 (Punch et al. 1992; Lin et al. 1992; Macomb et al. 1995; Schubnell et al. 1996; Gaidos et al. 1996; Quinn et al. 1996; Catanese et al. 1997; Bradbury et al. 1997; Schubnell 1997).

2 Thousands of Planets In Circumstellar Rings?

Recent observations with the Hubble Space Telescope of the Helix Nebula, the nearest planetary nebula at an estimated distance of 150 pc, have dis-

covered that the central star lights a circumstellar ring of about 3500 gigantic comet-like objects (“Cometary Knots”) with a typical mass of $M_c \sim 1.5 \times 10^{-5} M_\odot$ (O’Dell and Handron 1996) comparable to our solar system planets ($M_{Earth} = 3 \times 10^{-6} M_\odot$, $M_{Jup} = 9.6 \times 10^{-4} M_\odot$) and a total mass of $\sim 10^{-2} M_\odot$. The gaseous heads of these Cometary Knots have a typical size of about $r_c \sim 10^{15} cm$ and an average column density of $M_c / \pi m_p r_c^2 \sim 10^{22} cm^{-2}$. They look like ionization bounded neutral clouds, but it is not clear whether they contain a solid body or uncollapsed gas. They are observed at distances comparable to our own Oort cloud of comets, but they seem to be distributed in a ring rather than in a spherical cloud like the Oort cloud: The Helix Nebula has a structure of a ring lying close to the plane of the sky. The Cometary Knots are not seen close to the central star, but become very numerous as one approaches the inner ring and then become fewer out in the main body of the ring (perhaps, because it becomes more difficult to detect them there against the bright background). This suggests a ring rather than a spherical distribution, since no foreshortened objects close to the direction of the central star are seen. It is possible that the Cometary Knots have been formed together with the central star (O’Dell and Handron 1996) since star formation commonly involves formation of a thin planar disk of material possessing too high an angular momentum to be drawn into the nascent star and a much thicker outer ring of material extending out to several hundreds AU (Beckwith 1995). Evidence for this material has been provided by infrared photometry of young stars and also by direct imaging of this material (O’Dell and Wen 1994). The observation of comets of very long period and unconfined to the ecliptic plane gave rise to the idea of the Oort cloud of billions of comets in our Solar System at distances out to many tens of thousands of AU (Oort 1950). It is argued that small gravitational perturbations have circularized their parking orbits where occasionally another perturbation puts them into an orbit which brings them into the inner planetary system where they are finally viewable as comets. The mass distribution of the observed comets has been determined over only a small range since there are observational selection effects acting against finding the small ones and there are very few large ones. It is possible that the Cometary Knots are the high mass end of the vastly more numerous low mass comets (O’Dell and Handron 1996) and are confined to the ecliptic plane because of their relatively larger masses. In this paper we propose that most stars are surrounded with circumstellar rings which contain thousands of planets.

These loosely bound planets are stripped off from their mother stars by gravitational collisions in dense stellar regions. They are ablated by collisions and the strong radiation field near the massive central black hole in AGN and form their Broad Emission-Line Region (BLR).

3 Broad Emission-Lines Clouds In Quasars

Detailed studies of broad optical and ultraviolet emission-lines, whose atomic physics is well understood, have been used to obtain detailed information on the BLR of AGN. From their line-shapes, relative strengths and their time-lag response to the variations with time of the central continuum source, it was concluded that the BLR consists of a very large number $> 10^6$ of ionization bounded neutral clouds that move with very large random velocities and produce the broad emission-lines. The column density and mean density of the broad emission-line clouds and consequently their mean size, were estimated from the ionizing flux of the central source and the relative line strengths from the partially ionized clouds. Quite high densities and column densities were inferred. Typical values are, $N_p \sim 10^{22-25} \text{ cm}^{-2}$ and $n_p \sim 10^{10-12} \text{ cm}^{-3}$, respectively. For spherical clouds of uniform density, $\bar{N}_p = (4/3)n_p r_c$. Consequently, the radii of the clouds are typically, $r_c \sim 10^{13 \pm 1} \text{ cm}$. The velocity distribution of the clouds has been estimated from the profiles of the broad emission lines. Their full widths at half maximum indicate typical velocities of a few 10^3 km s^{-1} extending beyond 10^4 km s^{-1} at the base of the lines. Reverberation mapping has clearly established that the velocities are not a radial flow (Maoz 1997). The size of the BLR has been estimated from reverberation mapping of both Seyfert 1 galaxies (e.g., Peterson 1993) and quasars (e.g. Maoz, 1997), with typical lag times between 10 days for Seyfert 1 galaxies and 100 days for quasars, respectively. Typically, $R_{BLR} \approx 3 \times 10^{16} L_{44}^{1/2} \text{ cm}$, where $L = L_{44} \times 10^{44} \text{ erg s}^{-1}$ is the luminosity of the AGN in ionizing radiation. The velocities of the clouds seem to be consistent with those expected for clouds orbiting massive black holes, $v_c \approx \sqrt{GM/R} \approx 1.15 \times 10^9 \sqrt{M_8/R_{16}} \text{ cm s}^{-1}$, where $M = M_8 \times 10^8 M_\odot$ is the mass of the black hole and $R = R_{16} \times 10^{16} \text{ cm}$ is the distance from the black hole. The total number of clouds in the BLR was estimated from the sizes of the BLR and clouds and the covering factor C , i.e., the fraction of the AGN sky covered

by clouds. The latter was estimated from the ratio of Ly α photons emitted by the clouds to the H ionizing photons produced by the central continuum. Typically, $C \sim 0.1$. Assuming $C \ll 1$, one finds $N_c = (4/3)CR_{BLR}^2/r_c^2$. i.e., typically, $N_c \sim 10^6 - 10^9$. This number is consistent with the number of Cometary Knots expected in a galactic core like that of our Milky Way galaxy with typically $\sim 10^6$ stars within its inner 1 pc and $\sim 10^3$ per star.

4 Relativistic Jets As Cosmic Accelerators

GeV γ -rays have been detected from more than 50 active galactic nuclei (AGN) by the Energetic Gamma Ray Telescope Experiment (EGRET) on the Compton Gamma Ray Observatory (e.g., von Montigny et al. 1995; Thompson et al. 1995), all belonging to the blazar type of AGN. TeV gamma ray emissions have been observed only from the two nearest BL Lac objects, Mrk 421 at redshift $z=0.031$ and Mrk 501 at redshift $z=0.033$ (Punch et al. 1992; Lin et al. 1992; Macomb et al. 1995; Gaidos et al 1996, Quinn et al 1996; Schubnell et al. 1996; 1997). But, it has been suggested that perhaps all γ -ray blazars emit TeV γ -rays and the opacity of the intergalactic space to TeV photons due to e^+e^- pair production on infrared background photons prevents us from seeing them in TeV photons (e.g., Stecker et al. 1993).

The observed emission of GeV and TeV γ -rays requires a power-law spectrum of accelerated particles which extends to very high Lorentz factors, much higher than the typical bulk Lorentz factors, $\Gamma_b \leq 10$, of AGN jets (see, e.g., Guerra and Daly 1997). The observed GeV and TeV γ -rays from blazars must be emitted from the relativistic jets far out from the central object. This is because near the central object acceleration to very high Lorentz factors is prevented by fast inverse Compton cooling of electrons which are coupled by Coulomb interactions to protons. It is also required in order to avoid self absorption by e^+e^- pair production. It is still not known how such relativistic jets are formed in AGN, what is their particle composition, and how they accelerate particles to very high energies with a power law spectrum. Here we outline a simple mechanism by which relativistic jets with bulk Lorentz factors of only ≤ 10 may accelerate particles to very high energies with a power-law spectrum $dn/dE \sim E^{-\alpha}$ where $\alpha \sim 2.5$.

The high collimation of AGN jets over huge distances (up to hundreds of kpc), the confinement of their highly relativistic particles, their emitted

radiations and observed polarizations, all indicate that AGN jets are highly magnetized, probably with a strong helical magnetic field along their axis. The UV light emitted from the AGN and the jet ionizes the interstellar medium (ISM) in front of the jet. The jet magnetic field then acts as a magnetic mirror and accelerates the ionized interstellar particles to highly relativistic energies through the Fermi mechanism (1949):

In the rest frame of a jet, which moves with a bulk Lorentz factor γ_b , the charged ISM particles are moving towards the jet with an energy $\gamma_b mc^2$ and are reflected back with the same energy by the transverse magnetic field in the jet. In the observer frame their energy is boosted to $E = \gamma_b^2 mc^2$. Each time such a charged particle is reflected by an external magnetic field (of the ISM or a star) back into the jet its energy is boosted further by a factor γ_b^2 . This efficient acceleration continues until the jet becomes non relativistic. Because of the small cross sections for binary collisions of relativistic particles and the low Lorentz factor of the jet bulk motion, the jet loses most its energy by acceleration of the ISM and not by direct radiation or by binary collisions with the ISM particles.

High resolution observations in radio (VLB and VLBI) and in optical (HST) wavelengths indicate that jet ejection from AGN and microquasars is not continuous but occurs in ejection episodes. Let us denote by M the total ejected mass in an ejection episode, by Γ_B its bulk Lorentz factor and by M_{ISM} the total mass of ionized ISM which is accelerated by M . For simplicity let us assume a pure hydrogenic composition (the generalization to an arbitrary composition is straight forward). Conservation of energy and momentum then reads approximately

$$d(Mc^2\gamma_b) \approx -d(M_{ISM})c^2\gamma_b^2. \quad (1)$$

Consequently, for an ISM with a uniform composition

$$\frac{dn_p}{dE} \approx \frac{M}{2m_p} \left[\frac{E}{m_p} \right]^{-3/2}; \quad E < \Gamma_B^2 mc^2. \quad (2)$$

Note that the $\sim E^{-3/2}$ power-law spectrum is independent of whether the jet has a conical geometry (transverse expansion) or a cylindrical geometry (transverse confinement) and it is the same for ions and electrons. The composition of the accelerated particles reflects the composition of the ionized matter in the ISM. If one assumes that the probability of an accelerated ion

to be reflected back (by ISM or stellar magnetic fields) into the jet decreases like $R_L \sim E^{-1}$ where R_L is the Larmour radius, and that it is independent of ion type (same charge to mass ratio), then repeated acceleration will produce a power-law spectrum,

$$\frac{dn_p}{dE} \approx \frac{\Gamma_B M}{2m_p} \left[\frac{E}{m_p} \right]^{-5/2}. \quad (3)$$

This power-law spectrum of the accelerated particles cuts off when the Larmour radius of the accelerated particles ceases to be small compared with the size of the ionized region and the range of the relativistic jet. One can check that the above picture yields an estimated range L of AGN jets that is consistent with observations: Let us assume that a fraction η of the accretion power $\dot{M}c^2$ is continuously converted into a relativistic kinetic energy of a jet which is injected into a solid angle $d\Omega = \pi\theta^2 \ll 4\pi$. Let $c_s \approx \sqrt{5kT/3m_p}$ be the sound speed in the ISM, i.e., the speed of ISM material which replaces the accelerated material. The jet propagates to a distance where it becomes non relativistic and the time it takes it to reach there becomes longer than the time it takes the ISM to replace the accelerated mass by new mass, $\eta\dot{M}L\theta/c_s \approx n_p m_p \pi \theta^2 L^3/3$. Consequently,

$$L = \left(\frac{3\eta\dot{M}}{c_s n_p m_p \pi \theta} \right)^{1/2} \quad (4)$$

For typical parameters, $\eta\dot{M} = M_\odot y^{-1}$, $T = 10^5 K$, $\theta \approx 3^\circ$, one obtains $L \approx 10 \text{ kpc}$ for $n_p = 1 \text{ cm}^{-3}$ and $L \approx 200 \text{ kpc}$ for $n_p = 10^{-3} \text{ cm}^{-3}$, respectively.

5 The Hadronic Collider Model For Blazars

Following Dar and Laor (1997) we propose that TeV γ -rays which are beamed towards the observer are produced through $pp \rightarrow \pi^0 X$; $\pi^0 \rightarrow 2\gamma$ when ‘‘Cometary Knots’’ from the BLR cross the jet near the line of sight. The quiescent emission is due to synchrotron emission and inverse Compton scattering of external photons or photons emitted from the jet. The quasi-quiescent emission is due to jet interactions with many, relatively distant, ‘‘Cometary Knots’’ in the BLR. Strong GRFs are produced when Cometary Knots with

large area of high column density cross the line of sight at relatively small distance from the central engine. The hadronic collider model for blazars predicts TeV γ -ray emission which strongly fluctuates with time and shows spectral evolution, even if jet ejection does not vary with time on short time scales. The exact properties of individual flares depend on many unknown parameters of both the Cometary Knots (their geometry, density distribution, speed and trajectory relative to the jet and line of sight) and the jet (geometry, exact orientation relative to the observer, particle composition and differential energy spectrum of its high energy particles as function of distance from the jet axis and along the jet). However, the general properties of the quasi-quiet emission and the flares can be estimated using some simplifying assumptions. Essentially, the results of the hadronic collider model of blazars (Dar and Laor 1997) are applicable here with the only substitution “clouds = Cometary Knots”. We summarize them briefly below:

Because of the exponential dependence of the production cross section for $pp \rightarrow \gamma X$ on the transverse energy of the produced γ -rays (Neuhoffer et al. 1971; Boggild and Ferbel 1974; Ferbel and Molzon 1984), most of the γ -rays, which are seen by the observer when a gas cloud crosses the line of sight at a distance R from the central black hole, must arrive from impact parameters smaller than the critical impact parameter $b_c \approx RE_0/E_\gamma < R\theta_{jet}$, where E_0 is the average transverse energy of the produced γ -rays ($E_0 \sim 0.16 \text{ GeV}$ is independent of incident energy). The number of clouds with $b < b_c$ in the BLR is $N_c E_0^2 / 4E_\gamma^2$. A quiescent background is formed by jet-cloud interactions only if this number is large, i.e., if $E_\gamma \ll E_{crit} \approx \sqrt{N_c} E_0 / 2 \approx \sqrt{C_{0.1} L_{44}} / r_{12} \text{ TeV}$, where $r_c = r_{12} \times 10^{12} \text{ cm}$. In that case the jet produces a quiescent γ -ray flux of

$$\frac{dI_\gamma}{dE_\gamma} \approx C \bar{N}_p \sigma_{in} I A E_\gamma^{-\alpha}. \quad (5)$$

and the BLR acts as a target with an effective column density of $C \bar{N}_p$, as long as $E_\gamma > E_0/\theta_{jet}$ (below this energy the produced γ -rays are not beamed effectively towards the observer). For $E_\gamma > E_{crit}$ the BLR emission is expected to fluctuate considerably. A strong flare relative to the quasi-quiet background is formed when a cloud with a high column density crosses the line of sight at relatively a small R . If the radius r_{eff} of the area with a high column density is larger than the critical impact parameter, i.e., $r_{eff} > RE_0/E_\gamma$, then when the cloud blocks the line of sight, the γ -ray

flux at photon energies $E_\gamma > (R/r_{eff})E_0 \sim 1.6R_{16}/r_{12} \text{ TeV}$ flares up with a maximum intensity,

$$\frac{dI_\gamma}{dE_\gamma} \approx N_{eff}\sigma_{in}IAE_\gamma^{-\alpha}, \quad (6)$$

where

$$N_{eff} \approx \int_0^{b_c} d^2b [1 - e^{-\sigma_{in}N_p}] / \pi b_c^2 \sigma_{in} \quad (7)$$

is the effective column density. Thus, the maximal intensity contrast of TeV GRFs compared with the quiescent emission is $N_{eff}/C\bar{N}_p \approx 10 - 100$. The total duration of strong TeV emission in such flares is of the order of the time it takes the core of the cloud to cross the line of sight, i.e.,

$$T \sim r_{eff}/v_c \sim 10^3 r_{12} R_{16}^{1/2} M_8^{-1/2} \text{ s}. \quad (8)$$

The mean time between such strong flares is

$$\Delta t \approx (R_{BLR}E_0/Cr_{eff}E_\gamma)T(E_\gamma) \approx 50L_{44}^{1/2}/C_{0.1}E_{TeV}r_{12}]T \quad (9)$$

where $C = 0.1C_{0.1}$. For $E_\gamma < 1.6R_{16}/r_{12} \text{ TeV}$ the maximal GRF intensity is reduced by $(r_{eff}E_\gamma/RE_0)^2$ and the duration of the GRF is approximately the time it takes the cloud to cross the beaming cone:

$$T \sim RE_0/v_c E_\gamma \sim 1.4 \times 10^6 (R_{16}^{3/2}/E_{GeV}^{-1} M_8^{-1/2}) \text{ s}. \quad (10)$$

Hence the GRF has the following general behavior when a cloud crosses the line of sight at a distance R : At energies well below $E_\gamma \sim 1.6R_{16}/r_{12} \text{ TeV}$, the intensity contrast increases with increasing energy while the duration becomes shorter. Above this energy both the intensity contrast and the duration become independent of energy. This behavior results in a spectrum which becomes harder when the intensity increases and softens when the intensity decreases. The averaged quasi-quiescent emission spectrum therefore is softer than the spectrum of strong flares at peak intensity.

The above predicted properties of the quiescent emission and the flaring of blazars in TeV γ -rays seem to be supported by the observed properties of TeV flares and quasi-quiescent emission from Mrk 421 and Mrk 501 (Punch et al. 1992; Lin et al. 1992; Kerrick et al. 1995; Macomb et al. 1995; Quinn et al. 1996; Gaidos et al 1996; Schubnell et al. 1996; Catanese et al. 1997).

5.1 Production Of Neutrinos

Hadronic production of photons in diffuse targets is also accompanied by neutrino emission through $pp \rightarrow \pi^\pm X$; $\pi^\pm \rightarrow \mu^\pm \nu_\mu$; $\mu^\pm \rightarrow e^\pm \nu_e \nu_\mu$. If the incident protons have a power-law energy spectrum, $dF_p/dE = AE^{-\alpha}$, and if the cloud is transparent both to γ -rays and neutrinos, then because of Feynman scaling, the produced high energy γ rays and neutrinos have the same power law spectrum and satisfy (e.g., Dar and Shaviv 1996):

$$dI_\nu/dE \approx 0.7dI_\gamma/dE \sim E^{-\alpha}. \quad (11)$$

Consequently, we predict that γ -ray emission from blazars is accompanied by emission of high energy neutrinos with similar fluxes, light curves and energy spectra. The number of ν_μ events from a GRF in an underwater/ice high-energy ν_μ telescope is $SN_A T_{GRF} \int R_\mu(d\sigma_{\nu\mu}/dE_\mu)(dI_\nu/dE)dE_\mu dE$, where S is the surface area of the telescope, N_A is Avogadro's number, $\sigma_{\nu\mu}$ is the inclusive cross section for $\nu_\mu p \rightarrow \mu X$, and R_μ is the range (in $gm\ cm^{-2}$) of muons with energy E_μ in water/ice. For a GRF with $I_\gamma \sim 10^{-9}\ cm^{-2}s^{-1}$ above $E_\gamma = 1\ TeV$ and a power index $\alpha = 2$ that lasts 1 day, we predict 3 neutrino events in a $1\ km^2$ telescope. Since the universe is transparent to neutrinos, they can be used to detect TeV GRFs from distant γ -ray blazars. If the reported GeV GRF from the brightest EGRET γ -ray blazar PKS 1622-297, which had a maximal flux of $I_\gamma \sim 1.7 \times 10^{-5}\ cm^{-2}s^{-1}$ photons above 100 MeV (Mattox et al 1997), was accompanied by a TeV GRF it could have produced $\sim 30\ \nu_\mu$ events within a day in a $1\ km^2$ neutrino telescope..

6 X-Ray, MeV and GeV GRFs

Hadronic production of TeV γ -rays is also accompanied by production of TeV electrons and positrons mainly via $pp \rightarrow \pi^\pm X$; $\pi^\pm \rightarrow \mu^\pm \nu_\mu$; $\mu^\pm \rightarrow e^\pm \nu_e \nu_\mu$. Their production suddenly enriches the jet with high energy electrons. Due to Feynman scaling, their differential spectrum is proportional to the γ -ray spectrum

$$dI_e/dE \approx 0.5dI_\gamma/dE \quad (12)$$

and they have the same power-index α as that of the incident protons and the produced high energy photons and neutrinos. Their cooling via synchrotron emission and inverse Compton scattering from the internal (jet) and external

(cloud) magnetic and radiation fields, respectively, produce delayed emission of γ -rays, X-rays, optical photons and radio waves with a differential power-law spectrum (assuming no absorption in the cloud)

$$dI_\gamma/dE \sim E^{-(\alpha+1)/2}, \quad (13)$$

where $(\alpha+1)/2 \approx 1.75 \pm 0.25$. Hence, emission of TeV γ -rays is accompanied by delayed emission (afterglows) in the γ -ray, X-ray, optical and radio bands.

The peak emission of synchrotron radiation by electrons with a Lorentz factor Γ_e traversing a perpendicular magnetic field B_\perp (Gauss) in the jet rest frame which moves with a bulk Doppler factor $\delta = (1 - \beta \cos \theta)/\Gamma$ occurs at photon energy (Rybicki and Lightman 1979) $E_\gamma \sim 5 \times 10^{-12} B_\perp \Gamma_e^2 \delta$ keV. The electrons lose $\sim 50\%$ of their initial energy by synchrotron radiation in

$$\tau_e \approx 5 \times 10^8 \Gamma_e^{-1} B_\perp^{-2} \delta \text{ s} \approx 1.2 \times 10^3 B_\perp^{-3/2} E_\gamma^{-1/2} \delta^{-1/2} \text{ s}. \quad (14)$$

Consequently, the time-lag of synchrotron emission is inversely proportional to the square root of their energy. It is small for γ -rays and X-rays but considerable (\sim hours) for optical photons and (\sim days) for radio waves. The time variability of the intensity in different energy bands decreases with frequency. The integrated afterglow energy over the radio-optical-X-ray and γ -ray bands is limited by the total electron energy to less than $\sim 50\%$ of the total energy in the TeV GRF. The spectral evolution of the afterglow is a convolution of the spectral evolution of the production of high energy electrons and their cooling time. It is hardest around maximum intensity and softens towards both the beginning and the end of the flare. Because of electron cooling the spectrum should be harder during rise time than during decline of the flare. Such feature features seem to have been observed by ASCA (Takahashi et al. 1996) in the X-ray flare (XRF) that followed the TeV GRF from Mrk 421 on May 15, 1995.

7 Discussion and Conclusions

The observed GeV and TeV γ -ray emissions from blazars are usually interpreted as produced by inverse Compton scattering of highly relativistic electrons in the jet, on soft photons, internal or external to the jet, (e.g., Maraschi et al. 1992, Bloom and Marscher 1993, Dermer and Schlickeiser

1993; 1994, Coppi et al. 1993; Sikora et al. 1994; Blandford and Levinson 1994; Inoue and Takahara 1996). Although quiescent radio, X-ray and γ -ray emissions are naturally explained by synchrotron radiation and inverse Compton scattering of high energy electrons in the jet, there are inherent difficulties in explaining TeV γ -ray emission as inverse Compton scattering of soft photons by highly relativistic electrons or positrons in pure leptonic jets. The main difficulty is the fast cooling of electrons and positrons by inverse Compton scattering in the very dense photon field near the AGN (Levinson 1997), when they are accelerated to the very high energies required for the production of multi TeV γ rays. Moreover, such a model does not provide a natural explanation for the very short time-scale variability of the emitted high energy radiations (because of limited statistics the exact short time variability is probably not known yet). In this letter we have proposed an alternative model for TeV emission from blazars based on the assumption that AGN jets accelerate normal hadronic matter (e.g., Mannheim and Bierman 1992). TeV γ -rays are produced efficiently by the interaction of the high energy protons accelerated by the jet with gas targets of sufficiently large column density that cross the jet. Such gas targets could have been stripped off from the circumstellar rings around stars that orbit near the central black hole. Thousands of such gigantic cometary like objects have been discovered recently with HST in a ring around the central star in the Helix nebula. Their properties and number can account for the broad emission line clouds in AGN. The simple properties of hadronic production of high energy γ -rays, which are well known from lab experiments, together with the properties of the gigantic cometary knots can explain both the observed quasi-quiescent emission and the TeV γ -ray flares from blazars. We also predict prompt emissions of TeV neutrinos with comparable fluxes and delayed emission (afterglows) from GRFs in the γ -ray, X-ray, optical and radio bands with comparable integrated energies. Detailed predictions depend on many unknown parameters, but many general predictions do not depend on their choice and they seem to agree with the observations of high energy γ -ray emissions from Mrk 421 and Mrk 501. They seem to support an hadronic origin of TeV γ -rays emission from blazars. Although further observations of TeV γ -ray emission and other emissions from blazars may provide more supporting evidence for the hadronic nature of AGN jets, a decisive evidence will probably require the detection of TeV neutrino fluxes from Blazars, perhaps by the proposed 1 km^3 neutrino telescopes.

Acknowledgment: The authors would like to thank A. Laor for useful discussions.

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